Aircraft (Dornier 328) Tire Wear Reduction Using Six Sigma and DMAIC Methodology

Ma. Corazon P. Rubido
Researcher
Industrial Engineering Department, Adamson University
ma.corazon.rubido@adamson.edu.ph

Lourdes Lasian
Co-adviser
Chairperson, BSIE
Adamson University
lourdes.lasian@adamson.edu.ph

Noe D. Enriquez, PIE, ASEAN Eng.
Adviser
Director, IPPDO
Adamson University
noe.enriquez@adamson.edu.ph

Abstract

The purpose of this research study aimed to determine different factors and conditions affecting the tire tread wear of a Dornier 328 aircraft. So many studies and experiments were done to reduce aircraft tire wear, but none were patented because most literature describing the physical process that causes aircraft tire rubber to vaporize under landing loads is sparse, although multiple studies have been reported in the automotive field. The methodology used was the Six Sigma and DMAIC methodology. To analyze the gathered data from the maintenance logbook of an aircraft charterer, the researcher also used the Design of Experiment. Based on the results of the experiment, three factors are statistically significant to the aircraft tire wear: the experience of the pilot, the length of the runway, and the age of the aircraft. Also, tests were used to determine the interaction between factors, and as a result, the 2-way interaction of pilot and runway gives the most significant interaction. These findings will help the charterer reduce their operational costs by minimizing the tire tread wear and also aid them in planning their flight schedules in consideration of the manning of the aircraft and its destinations. Also, a decrease in rubber production for new tires will have a positive environmental impact. The findings will also serve as a guide for further studies by future researchers on other factors that might be contributory to the reduction of tire tread wear which the researcher was not able to consider due to some constraints.

Keywords

aircraft tire wire, Six Sigma, DMAIC, Design of Experiment

1. Introduction

Six Sigma methodology focuses on business improvement. Any company wanting to improve numbers must decrease the number of defective products or services as its output. A defective product (tire wear) can harm customer satisfaction levels as well as their safety. A company that wants to implement Six Sigma principles has to find a way to minimize cost wherever possible without reducing quality and compromising security.

For the aviation industry, it is always a question of the quality assurance process that applies to aviation maintenance. It is hard to answer because aviation maintenance is governed by factors such as the original equipment maker (OEM), aircraft maintenance manual, industry standards and specifications (SAE, ANSI, NAS), and general maintenance practices. Therefore, if a maintenance situation does not follow any of these documents or procedures, the experience or guidance from another senior technician or inspector to accomplish the repair must be followed.

Quality assurance needs people in the aviation industry who are both well versed in aircraft maintenance and able to adapt to the quality culture embodied in ISO 9001. In aviation quality assurance (QA), there is a mix of several occupations and abilities, such as technical and troubleshooting skills, engineering, psychology, philosophy, and diplomacy. It is a vital part of every aircraft maintenance operation, regardless of size.

The most important person in ensuring an aircraft's passenger's airworthiness and safety are aircraft maintenance technicians (professionals). They are the ones who perform the inspections to ensure the quality and airworthiness of an aircraft during routine maintenance. These tasks include replacing worn or damaged components, testing engine operations to detect malfunctions, and inspecting engine parts for wear, warping, and leaks.

The decision to select the topic was based on the summary of the data gathered from their maintenance logbook. One of the company's top 3 maintenance problems is tire wear which conditions are needed for placement. The company's safety director says they spend approximately $25,500 annually retreading and replacing worn aircraft tires due to the high friction created when the aircraft touches down on the runway.

1.1 Objectives

The overall objective of this project is to study factors and conditions that greatly affect aircraft tire wear. By knowing these factors and conditions, we can reduce tire wear significantly and eventually increases the pesos being saved annually. It will also decrease the amount of rubber used to produce new tires, therefore having a positive environmental impact.

1.1.1 This study was aimed at extending the life cycle of aircraft tires.
1.1.2 Identify the different factors and conditions which significantly affect aircraft tire wear.
1.1.3 Identify solutions for extending the life cycle of aircraft tires using the Six Sigma principles and the DMAIC methodology.

2. Literature Review

There is rarely literature describing the different physical process which causes the rubber of an aircraft to vaporize under landing loads. However, in the automotive field, there are multiple studies done as far as tire skid marks are concerned. Automotive skid marks are caused by material being removed by abrasion between the slipping tires and the asphalt runway surface.

According to Persson (2006), the friction force caused between the tire and the rough surface, or the asphalt of the runway is the result of internal friction of the rubber, which happens when atoms or molecules interact with one another. This internal friction can cause heating of the tire material resulting in smoke being produced.

Based on the study of Padovan and Kazempour (1990), he built an energy-balance model to compute the work rate due to interfacial friction between tire and runway surfaces and determine its effect on the growth of wheel rotary inertia and slip work. And it was concluded after various simulations that tire wear was increased with horizontal landing speed, sink rate, and surface friction coefficient.

A scientist named Slagmaat (1992) investigated various suitable models for simulating longitudinal aircraft tire dynamics and found that the Pacejka models, popular in automotive literature, were not eligible to represent the fast dynamics in aircraft landings even though significant simplifications were applied to Pacejka tire model such as a multi-body nonlinear landing gear model for vertical tire load simulations. Comparisons with experimental results were not made due to a lack of reliable experimental data availability. Another invention, an aircraft wheel spinner, was designed to prevent the aircraft from landing smoke. Though patented, no aircraft industries use these patents because there is no valid proof of the system that those patents define validated to eliminate landing smoke which eliminates tire wear. Until now, aircraft landings continue to generate smoke, produce screeching sounds, and the need to replace the tires due to accumulated damage over time periodically; this study would want to address the main issue.

Horvath and Szoke (2006) suggested that instead of adding an assembly to the wheel, alter the tire's design to incorporate curved airfoils on both sides of each tire. This will minimize protrusion. Another suggestion was to attach the foils to existing tires but ensure that the material is durable using rubber or synthetic rubber and closed or open cell foam. This material can be bonded to the carcass plies by nylon fabric and covered with rubber or other synthetic materials. The concept was good, but such a design would require all new wheel assemblies and enclosures to accommodate them, which is neither cost-effective nor feasible. Horvath and Szoke have not executed their idea in real-world testing. You might ask if more plies are necessary to classify an aircraft tire as stronger than the one specified by the manufacturer. The answer is no because more plies decrease the interior diameter of the tire; it also makes a tire hotter. These are the reasons why it affects the way a tire performs.

2.1 Aircraft Landing Gear

The principal support of the airplane during landing is the landing gear. This is used to absorb the landing impact energy to minimize the loads transmitted to the airframe. The tires of the landing gear are designed to withstand hefty loads. The number of tires required for an aircraft depends on the plane's weight. Tire tread patterns were designed to facilitate stability in high crosswind conditions, for braking effect, and to channel water away to prevent hydroplaning. These aircraft tires are usually inflated with nitrogen to minimize expansion and contraction from extreme changes in immediate surrounding temperature and pressure experienced during flight. Using inert gas such as nitrogen for tire inflation instead of air will eliminate the possibility of a tire explosion.

2.2 Aircraft Tire Care and Maintenance

Aircraft tires were manufactured to the highest standards because every landing requires aircraft tires to accelerate from the standing still to touchdown speed in seconds. Only the best docks exert significant twisting forces between the tire tread and bead as the tire accelerates to touchdown speed, not to mention the crosswind component and the accompanying loads of an aircraft. It is essential to focus on the tire inspections during the pre-flight schedule, ensuring that the tires are in excellent condition. Frequent checks of tires must be explicitly done after tricky landings. A good tire inspection may include a close examination of cuts, worn spots, bulges, foreign objects embedded in the tread, and general tread wear by measuring tire tread depth. Some tire manufacturers publish minimum tread depths, which require tire replacement. But as a rule, if the tire tread has been worn to the base of any groove anywhere on the tire, it should be replaced. It is also essential to check if any of the inner fabric structure is showing through the tire tread, regardless of the tread depth; this needs to be replaced because this indicates a severe condition. Lastly, examine the tread wear for evenness. There are cases wherein the tread is worn at the center but not on the edges; the tire is probably over-inflated. In other cases, if the tire shows more wear on the edges. It means that it is under-inflated. Aircraft tires are primarily made of natural rubber, so monitoring their air pressure is essential because they can lose pressure over time. If not properly monitored, this can lead to uneven wear, excess heat generation, and reduced traction. Although aircraft tires are manufactured to extremely high standards to withstand a surprising amount of abuse and still return you safely on the ground, tire maintenance should not be neglected. Always check air pressure regularly and inspect aircraft tires pre- and post-flight.

2.3 Aircraft Tire Wear Limits

All aircraft tires experience wear, specifically during taxiing, take-off, and landing. But among the three operations, take-off generates the most tire wear because the aircraft has a full fuel load, and the tires are pre-heated during taxiing. The first thing to check (after checking the air pressure) when inspecting aircraft tires is the amount of remaining tread to avoid excessive wear and unsafe conditions during flight. Aside from the three operations stated, other excessive operations might cause the print to wear much faster, such as high-energy braking, high-speed taxiing, and high-speed cornering. Therefore, it is essential to know the limits of acceptable aircraft tire wear and take the time to conduct proper inspections to get the most out of your tires.

2.4 Engineering and Technical Information

In designing aircraft tires, standardization of terms is very important to ensure that it is understood by all the users, suppliers, and manufacturers. , For a newly designed aircraft, the selection of Main Wheel Tires should consider having allowances to increase load-bearing capability and considering that aircraft designs are eventually modified to accommodate heavier versions to meet operator requirements. Selecting a tire that permits an increased load capability will help avoid the costly necessity of changing tire size or wheel details required to support heavier aircraft versions. In selecting the Nose wheel tire, care should be taken in reviewing both the static load requirement and a dynamic condition to avoid possible future retrofitting.

It focuses on general aviation, specifically light aircraft, which usually weigh 2200 pounds at the landing and land at 70 mph. To stop this aircraft, all the kinetic energy must be removed, but according to Newton, energy cannot be created or destroyed, so it must be converted into some other sport. Before a tire can be measured, it must be mounted on its proper rim, inflated to the pressure given in the Tire Manual, it should be allowed to stand for at least 12 hours at room temperature, and the pressure checked. A tire should not be permitted for use if the brake heat results in temperatures exceeding 300^0F at wheel surfaces adjacent to the tire and tube.

2.5 Aircraft Landing with A Thud

Rough landings were experienced occasionally by even the best pilots, according to Chris Cooke (2015). According to him, it usually happens when the pilot is not entirely comfortable with how it handles close to the ground or if the pilot is new to a particular aircraft. Landing an aircraft smoothly and safely is challenging, especially if numerous variables are involved. One major factor for this is the pilot's experience level landing the plane. In the U.S, pilots are only authorized to fly one aircraft type at a time. They believed that as a pilot gains seniority with a company, they will progress to bigger aircraft. Also, experience levels vary with flight time in a particular plane. Providing smooth landings is one-way pilots show their skill and finesse; this is what all pilots strive to achieve.

2.6 How to Perform a Good Landing

Every pilot aims to have a good landing for every flight they have because landing is one of the most critical phases during a flight. This is the second thing pilots learn in training after basic flight controls and recovery techniques. There is a wrong connotation by many that a soft landing is a good landing. This isn't always true, yes, it does make the ride more comfortable for our passengers, but if the conditions are not perfect and the runway is long, a soft landing can be a bad thing. This is because if the touchdown is very quiet, the aircraft is still half-flying, so it needs to be controlled carefully, taking more time to dump all the kinetic energy keeping the plane aloft. In the case of a wet runway, it needs a positive landing. Unless the runway is very long, a wet runway needs a positive landing, meaning the pilot must exert effort to make a firm touchdown onto the runway. This is because at the landing speed of anywhere between 220 and 280 km/hr. The water on the runway can't disperse under the tires in a soft landing, and this will cause the wheels will 'skate' on top of the water's surface (hydroplaning). A firm landing will control the wheels to force touchdown, which will break through this water film and contact the runway tarmac to lessen the slippery wet runway. Many passengers felt relieved when the aircraft landed on the runway and started clapping most of the time. They thought the landing was the end of their flight, but they got it all wrong because the aircraft was still traveling at great speed and was somewhat unstable. Anything can still go wrong, such as a sudden gust of wind could make one or even both wings airborne again. Therefore, when the pilot lands the aircraft; they still use flight controls to keep it centered and down on the runway until it is slowed down.

2.7 No Human Intervention During Automatic Landing Is a Myth.

Automatic landing is what we usually heard or read about in aviation industries. We tend to believe that pilot uses automatic landing because they are lazy and fly the aircraft on autopilot the whole time, even during landing. This is just a myth and far from the truth. The use of autopilot is intended to be used in conditions of insufficient visibility (as in fog and mist).

An automatic pilot uses control algorithms based on information from navigation radios on the ground and air sensors of the aircraft or airplane. There is no level of prediction or anticipation that only a human pilot can do. We cannot expect to use autopilot to sink a bit more or see a gust of wind rustle grass as it rushes towards the runway. That is why even when landing on an automatic pilot, one of the pilots will still be holding the controls if it does something wrong and ensure the landing is completed safely.

3. Methods

This study made use of the qualitative method using the Six Sigma Methodology. The Six Sigma projects for problem-solving, quality, r performance improvement often use the DMAIC framework. The DMAIC denotes the five critical phases or stages in the Six Sigma methodology, namely definition, measure, analysis, improvement, and control. The major activities that are executed at different phases of the DMAIC approach in this study are as follows:

3.1. Define Phase

The researcher during her industry immersion for 480 hours, conducted a study that aimed at gaining a better understanding of the aircraft tire wear problems and identifying possible approaches to extend aircraft tire life using the Six Sigma principles and the DOE methodology. The decision to choose the topic was based on the summary of the data gathered from the PSAI maintenance logbook, wherein the company's top maintenance problem is tire wear.

3.1.1. Methods of the Study

This chapter of the research study dealt with the procedures and techniques used by the researchers in completing the study. It includes the research design, description of the respondents, details on the sampling technique, validation, administration, techniques in data gathering, and statistical treatment used.

3.1.2. Research (Experimental) Design

The research design implied and which suites the research study was the Experimental Research Design, as it is used to determine the significant differences between factors affecting the lifespan of an aircraft tires, such as the difference between the flying skills of an experienced and a newbie pilot by experimenting, aiming to examine and manipulate a treatment or an intervention to prove or to disprove the given hypotheses (Knight, 2012). There are three different types of experimental research design: Factorial Experimental Design, Randomized Block Design, and Cross-over Design. Each type serves different purposes and can only be used in certain ways. The first type is known as the Factorial Experimental Design which is the design that manipulates two or more independent variables simultaneously to observe their effects on a dependent variable. The next type is the Randomized Block Design. In this type of survey research design, the inherent differences between experimental subjects and differences in experimental conditions are controlled. The last type will be the Cross-over Design wherein the subjects are exposed to more than one treatment unlike the other designs which are controlled to one treatment and the subjects are randomly assigned to different orders of the treatment given (Patidar, 2018). In this research study, the researchers made use of the Factorial Experimental Design, as this research design allows for the testing of two or more hypotheses in a single project. This design will provide the necessary information needed for this research study.

3.1.3. Respondents of the Study

The respondents of the study are the aircraft maintenance technicians and pilots from PSAI who are responsible for the recording of maintenance problems and repairs for the two aircraft.

3.1.4. Data Gathering Procedures

This study was composed of three types of variables namely the Control Variable, the Independent Variable, and the Dependent Variable. These variables are significant as these are the focus of this study.

Independent Variables
The independent variables present in this study are the skills (flying experience) of the pilot, the length of the runway, and the age (life value) of the aircraft used. These variables are the main focus of this study.
Dependent Variables
The dependent variables in this study are the number of times replacing the aircraft tires and the frequency of replacement for a duration of time.

Controlled Variables
The controlled variables are selecting a pilot to fly a particular aircraft and the number of days/months to base his gathering of data. These are the components that the researchers can control during the whole experimentation of the research.

Source of Data
The researchers made use of the following instrument and techniques to gain the proper information and knowledge about the different factors which has an impact on the lifespan of an aircraft tire.

3.2. Measure Phase

3.2.1. Experimentation Method
In this research study, the researchers used an Experimental Method in collecting the needed data and information. As asserted by McLeod (2012), it is a method in which the hypothesis is scientifically tested. In this, the independent variable is manipulated, and the dependent variable is measured; other variables are controlled.

The researchers chose this method because it is the exact method that will give the exact or accurate results. It has its advantages that may help in the process. According to Goddard (2,015), the researchers or the experimenter may control the variables to lessen the likelihood of the experiment failing. It can also confirm that the effects of the changes in the dependent variable are caused by the independent variable. This method can also be repeated multiple times to assure the collected data and be determined if it can be trusted.

3.2.2. Pre-Experimentation Activity
The researcher requested permission from the officials of the company to conduct the experimental study. The process of conducting the experiments is as follows:

Two aircraft will be used. One to be manned by a single pilot for three months and the other aircraft will be manned by different pilots (the usual scheduling system by the company).

Record the destinations of the pilot to man the aircraft for three months as well as the possible pilots to man the other aircraft.

a. Before the start of the experiment, the tires attached to the two aircraft must be checked for the tread depth conditions. It must be stated for strict compliance that the tires to be used must be of the same tread depth measurements.

3.2.3. Experimentation Activity

a. The researcher will check the maintenance logbook being used for the two aircraft every month for any untoward incidents that may cause a disruption to the continuation of the experiments.
b. Aside from checking the logbook, the researcher will provide a chart for the recording of tread measurements every month for the two aircraft.
c. Record the measurements of the tread depth of the tires used for the two aircraft as well as the tire defects incurred during the experiments (table will be provided as evidence of the results).

3.2.4. Post-Experimentation Activity
Determine if there is/are significant differences in the frequency of tire replacement due to damaged incurred from both aircraft. The gathered data were evaluated and with the results of the experiment, gained proper knowledge and valid information. This study might be the solution to lessen the occurrence of tire replacement by validating factors from the experiment which affect the life span of the aircraft tires.

3.2.5. Statistical Treatment of the Study
The data gathered were statistically treated using the Design of Experiment (DOE), to determine the relationship between factors affecting a process and the output of that process. The researcher made use of three factors at two levels namely: Pilot (newbie at 2 years of flying experience and experienced pilot with 10 years of flying experience); Runway short at a minimum of 1,000 meters and long at a maximum of 4,000 meters); and Aircraft (old and new).

4. Data Collection

4.1. The Experimental Design and Analysis

To determine which of the factors involved in the experiment greatly affect the aircraft tire tread wear, the factorial experimental design was used by the researcher. To investigate the extent of tire tread wear, the experimental design was carried out by choosing three factors (operational/process variables) effective on responses, namely: pilot, runway, and aircraft. These three factors were coded as A, B, and C respectively. They correspond to two levels such as experienced or newbie (pilot), long or short (runway), and old and new (aircraft). Factors and levels were given in Table 3.

Table 3. Experimental Factors and Levels

Standard Run Order	**Factors**		
	A: Pilot	**B: Runway**	**C: Aircraft**
1	Experienced	Short	Old
2	Experienced	Long	Old
3	Experienced	Short	New
4	Experienced	Long	New
5	Newbie	Short	Old
6	Newbie	Long	Old
7	Newbie	Short	New
8	Newbie	Long	New

The researcher uses numeric descriptions for pilot factors based on the data gathered namely: 2 years' experience for Newbie and 10 years' experience for Experienced pilot, same as for the runway, 1,000 meters for short runways and 4,000 meters for long runways, and the Aircraft, we used text such as old and new aircraft.

5. Results and Discussions

StdOrder	RunOrder	CenterPt	Blocks	Pilot	Runway	Aircraft	Tire Thread Measurement
1	1	1	1	2	1000	Old	5.800
2	2	1	1	10	1000	Old	5.720
3	3	1	1	2	4000	Old	5.800
4	4	1	1	10	4000	Old	6.380
5	5	1	1	2	1000	New	4.740
6	6	1	1	10	1000	New	5.055
7	7	1	1	2	4000	New	5.320
8	8	1	1	10	4000	New	6.285
9	9	1	1	2	1000	Old	6.380
10	10	1	1	10	1000	Old	5.965
11	11	1	1	2	4000	Old	5.965
12	12	1	1	10	4000	Old	6.325
13	13	1	1	2	1000	New	5.320
14	14	1	1	10	1000	New	4.740
15	15	1	1	2	4000	New	4.495
16	16	1	1	10	4000	New	6.350

Figure 3. Design matrix for the experiment

A 2^3 full factorial design was carried out to set the mathematical relationship and to represent how the aircraft tire tread wear depends on the pilot, runway, and aircraft. An experimental matrix was shown in Table 3. The running order for each run was not randomized to minimize possible systematic errors. Coded levels were given as 10 years for experienced pilots and 2 years for newbie pilots, 4,000 m. for long runways and 1,000 m. for the short runway, and lastly old and new or newer aircraft. (Figure 4)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	5.4479	0.77827	8.05	0.004
Linear	3	3.4751	1.15835	11.98	0.002
Pilot	1	0.6400	0.64000	6.62	0.033
Runway	1	0.5625	0.56250	5.82	0.042
Aircraft	1	2.2726	2.27256	23.50	0.001
2-Way Interactions	3	1.8027	0.60089	6.21	0.017
Pilot*Runway	1	1.2769	1.27690	13.21	0.007
Pilot*Aircraft	1	0.2475	0.24751	2.56	0.148
Runway*Aircraft	1	0.2783	0.27826	2.88	0.128
3-Way Interactions	1	0.1702	0.17016	1.76	0.221
Pilot*Runway*Aircraft	1	0.1702	0.17016	1.76	0.221
Error	8	0.7736	0.09670		
Total	15	6.2214			

Figure 4. Factorial Regression: Tire Thread Measurement versus Pilot, Runway, Aircraft

Based on the result of the ANOVA for the transformed response, the researcher can say that the three factors are all statistically significant to the study because the p-value is less than the alpha α=0.05. Though all of the three factors have significant interaction with the study, however, looking at the 2-way interaction, factors AB is statistically significant because the p-value is less than α=0.05. While for 2-way interaction, factors AC is not statistically significant because the p-value is greater than α=0.05 as well as for three-way interaction for factors ABC.

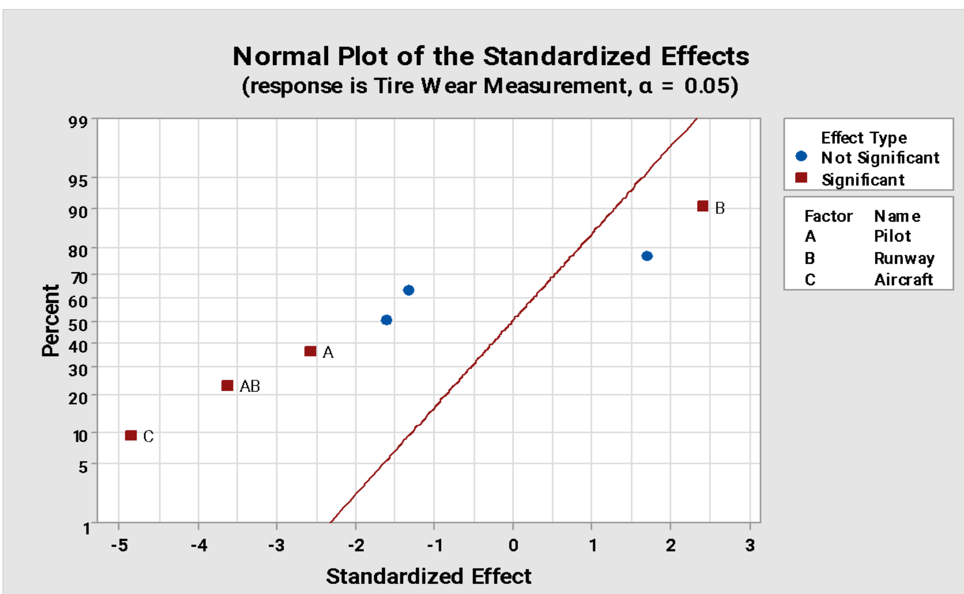

Figure 5. Interpreting the Effects of Plots

Based on the result of the Normal Plot of Standardized Effects, the red square symbol identifies significant terms. Pilot (A), Runway (B), Aircraft (C), and Pilot*Runway (AB) are significant because their p-values are less than the α of 0.05.(Figure 5)

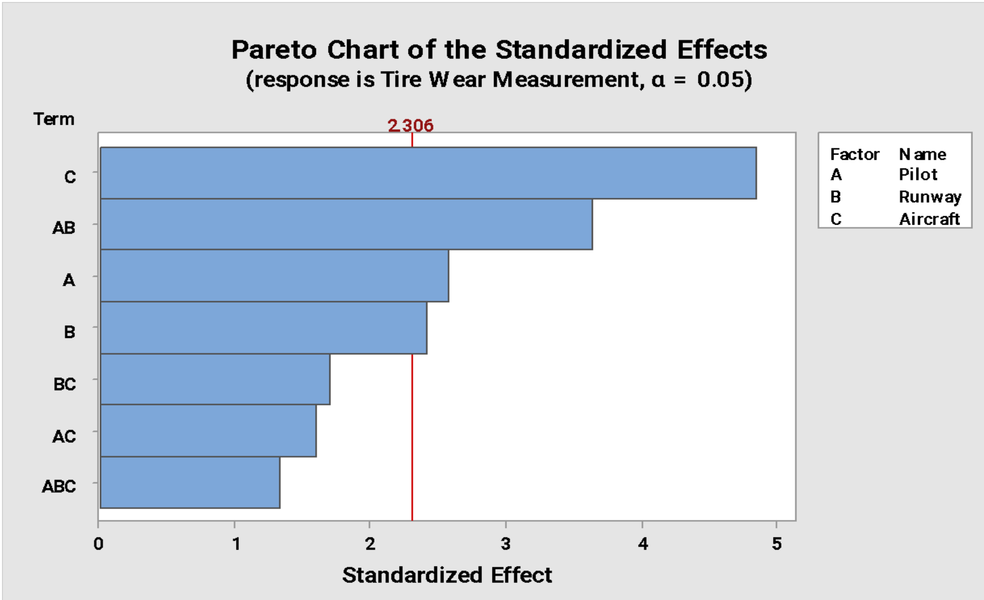

Figure 6. Pareto Chart on the Standardized Effects

Minitab values display the absolute value of the effects on the Pareto chart. Any effects that extend beyond the reference line (vertical dotted lines) are significant. Pilot (A), Runway (B), Aircraft (C), and Pilot*Runway (AB) are all significant. (Figure 6)

Factorial Plots for Tire Thread Measurement

Figure 7. Main Effect Plot for Tire Wear Measurements

The factorial plots include the main effects plot and the interaction plot. The main effect is a difference in the mean response between two levels of a factor. The main effects plot shows the means for *Tread*

Measurements using the controllable factors which are the Pilot and the Aircraft and the uncontrollable factor which is the Runway. The interaction plot shows the impact of the pilot's flying experience, the runway's length, and the aircraft's age, on the response. Because an interaction means that the effect of one factor depends on the level of the other factor, assessing interactions is important. (Figure 7)

Each point represents the mean processing time for one level of a factor. The horizontal center line shows the mean processing time for all runs.

The first panel of the plot indicates that the pilot's flying experience has a significant effect since the graph shows that the higher the flying experience of the pilot the lesser the mean of the tire tread measurements. The center panel of the plot indicates that the shorter the distance of the runway the lesser the mean of the tire tread measurements. The right panel of the plot indicates that the older the age of the aircraft, the higher the mean of the tire tread measurements.

If there were no significant interactions between the factors, the main effects plot would adequately describe the relationship between each factor and the response. However, because the interaction is significant, you should also examine the interaction plot. A significant interaction between two factors can affect the interpretation of the main effects.

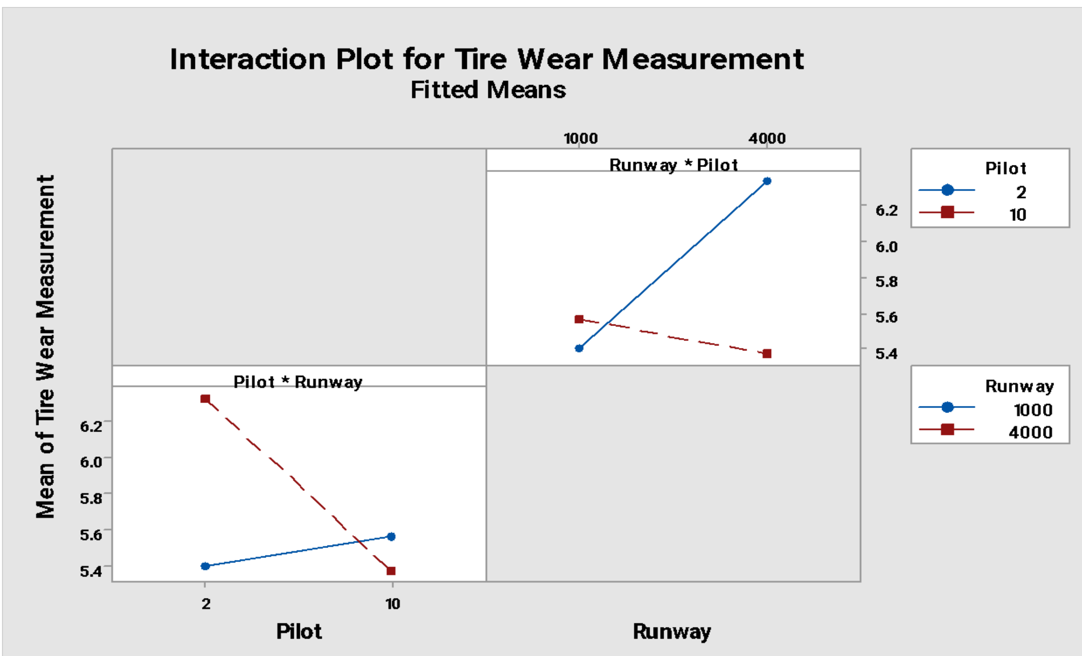

Figure 8. Interaction Plot for Tire Tread Measurements

Each point in the interaction plot shows the mean measurement of tire tread at different combinations of factor levels. If the lines are not parallel, the plot indicates that there is an interaction between the two factors. The interaction plot from the left panel indicates that the higher the flying experience of the pilot the lesser the mean of the tire tread measurements and from the right panel, the interaction plot indicates that the longer the distance of the runway, the higher the mean of the tire tread measurements. (Figure 8)

Cube Plot (fitted means) for Tire Thread Measurement

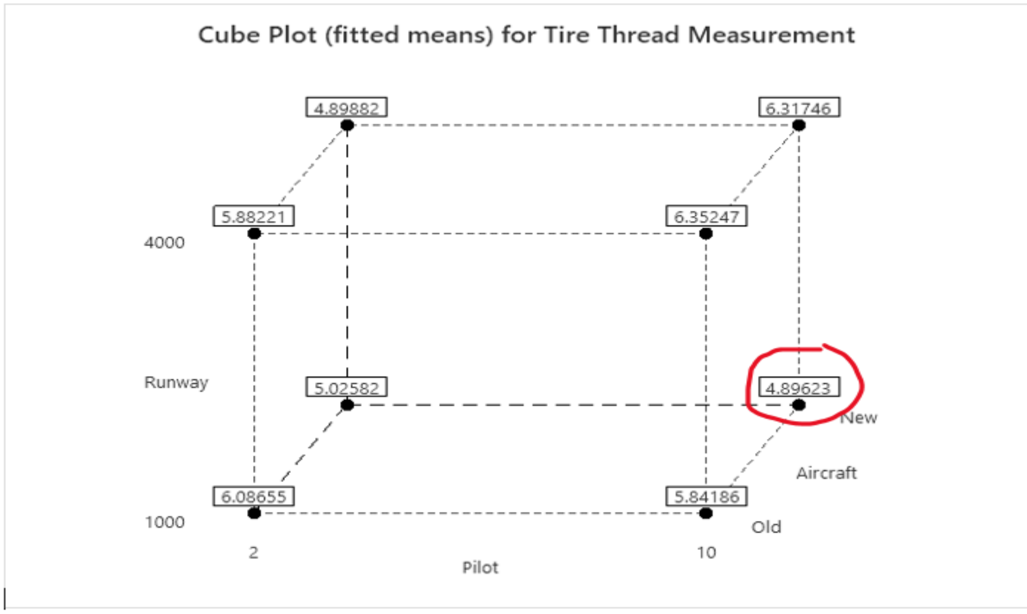

Figure 9. Cube Plot Analysis for Tire Tread Measurements

Fitted means are useful for assessing response differences due to changes in factor levels. For the measurements of tire tread, the cube displays all combinations of three factors at two levels and the fitted mean for each combination. Assessing the results of the means, we can see that from all combinations, the least of all the means is 4.89623, and to achieve that, the combination must be for the pilot to be experienced, the aircraft to be new and the runway to be short. (Figure 9)

6. Conclusion

It says that tire life is dependent on the specific pilot. Based on the result from the cube plot (fitted means) for tire tread measurements, we can see that to achieve the least mean (tire tread measurement), the pilot should be experienced, short runway, and new aircraft. Some pilots seem to impact the runway hard, which gives even less time for the up spinning off the tires, and certainly more wear on the tires. This is one of the advantages of having an experienced pilot handling the aircraft.

But we all know that the distance of runway to be used is our uncontrolled variable, we cannot always choose a destination with a short distance runway since an aircraft charterer always pleases its customers for business purposes. For the age of an aircraft to be used, the charterer makes the most of its life span and what they can do is to strictly implement their preventive maintenance so as not to shorten its life span as well as ensure that their aircraft is worthy of flying.

Based on the summary of the findings and conclusions presented, the following recommendations were offered:

1. Management of PSAI – to be aware of the importance of skills upgrading for their pilots so as not to limit their manning schedule to experienced pilots only but skilled pilots, (a pilot can be a newbie but skilled). It can be done by implementing a program for continuous training and attending seminars.

2. Pilots – One of the uncontrollable variables in the experiment/study is the runway, but a pilot can be a contributor in lessening the encounter of an aircraft running on a runway with soft spots and damaged areas which causes an aircraft tire to be damage. A pilot must maintain a reporting system for any encountered damaged part in the runway

(cracked, soft spot, or areas waiting for repair) to the dispatcher to be reported to the traffic controller and for the latter to issue a memorandum notice for issuance to all pilots' concerns.

Also, the pilot should minimize the use of hard breaking and instead use medium breaking to avoid damaging the tread of an aircraft tire.

For the non-optimal combinations, the following are recommended:

a. Newbie Pilot/ Old Aircraft/ Long Runway – avoid tight turns that place high lateral loads on tires. If tires were subjected to such conditions, these tires can experience external damage to the tread or sidewall, internal damage to the casing structure, or bead unseating with consequent pressure loss.
b. Newbie Pilot/Old Aircraft/Short Runway – avoid a hard landing which most newbie pilots experienced during short runways.
c. Experienced Pilot/Old Aircraft/ Short Runway – avoid a hard landing because an old aircraft might not fully support the tires compared to the new ones which might damage the tread or sidewall of the tires.
d. Experienced Pilot/Old Aircraft/Long Runway – long taxiing for an old aircraft but manned by an experienced pilot will not cause the same damage as if the pilot is a newbie which means that this combination still will not achieve the ideal combination to achieve the least damage to the tread of an aircraft.

3. Aircraft Maintenance Technicians – to be aware that no matter how experienced a pilot is to man the aircraft, still the safety of flying is also partly dependent on how well they maintained the airworthiness of the aircraft itself.

4. Future researcher – To verify and strengthen the results of this research study and may use other kinds of experimentation such as environmental factors like hotness or wetness of runway due to changing seasons which this researcher was not able to conduct due to several constraints.

References

Chris Cooke Why Your Flight May Land Wit a Thud (2012). (https://fortune.com/2015/12/22/smooth-airplane-landing/)
Horvath and Szoke inventors of Airplane tire saver by protrusion airfoils (2006).
Ochi, Y., & Kanai, K. Automatic approach and landing for Propulsion-controlled aircraft SanibeSanibel & Tsai, C. (1969). Tire wear model. *Interim Report*, *Issue 2*
Padovan, J., Kazempour, A., & Kim, Y. H. Aircraft landing-induced tire spin-up. *Journal of Aircraft, 28*(12), 849-854. (1990).
Slagmaat, V. M.T.P. Tire models in aircraft landing gear simulation. (1992).
Tanyolac, T. & Yasarcan, H. A soft-landing model and a mass-spring damper-based control heuristic. (2011).
Tomita, H. Friction coefficients between tires and pavements surfaces. (1964).
Tong, G., & Jin, X. Study on the simulation of radial tire wear characteristics.
Zhang, Y., Zhang, G., & Yu, F. Modeling and μ synthesis control of vehicle active suspension with the motor actuator. *WSEAS Transactions on Systems*, *11*(5), 173-186. (2012).
Zglimbea, R., Finca, V., Greaban, E., & Constantin, M. Research on parameter identification of modified friction LuGre Model-based distributions theory. (2009).

Biographies

Ma. Corazon Rubido. Engr. Ma.Corazon P. Rubido is the Chairperson of the Bachelor of Science in Industrial Engineering at PATTS College of Aeronautics. She finished her degree with a Bachelor of Science in Industrial Engineering from Adamson University. Also, a graduate of master's in management from the Technological University of the Philippines-Manila, a graduate of Secondary Education from the University of Perpetual Help – Molino, and a LET passer.

Lourdes Lasian is an Industrial Engineering Professor at Adamson University, Manila, Philippines**.** Engr Lasian holds a Bachelor of Science degree in Industrial Engineering from University of Sto Tomas and finished her master's degree in Business Administration from San Sebastian College-Recoletos Manila. She has 21 years of combined work experience both from Manufacturing and Service Industry. She has taught courses in management, feasibility and other professional course. She has published and presented research papers both local and international. She is formerly the Chairperson of Adamson University

Noe Enriquez. Engr. Noe D. Enriquez is the Director of Institutional Planning and Policy Development Office of Adamson University since 2008 to the present. He finished his degree in Bachelor of Science in Industrial Engineering degree from Adamson University. He later earned his Master of Business Administration in Ateneo de Manila. He also acts as Deputy Quality Management System representative in Adamson University.